

This article was downloaded by: [USDA Natl Agricultul Lib]

On: 3 June 2010

Access details: Access Details: [subscription number 731827463]

Publisher Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Journal of Plant Nutrition

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713597277>

MINERAL COMPOSITION OF FORAGE LEGUMES AS INFLUENCED BY ALUMINUM

V. C. Baligar^a; D. L. Grunes; D. P. Belesky^a; R. B. Clark^a

^a Appalachian Farming Systems Research Center, Beaver, West Virginia, U.S.A.

Online publication date: 03 May 2001

To cite this Article Baligar, V. C. , Grunes, D. L. , Belesky, D. P. and Clark, R. B.(2001) 'MINERAL COMPOSITION OF FORAGE LEGUMES AS INFLUENCED BY ALUMINUM', Journal of Plant Nutrition, 24: 2, 215 – 227

To link to this Article: DOI: 10.1081/PLN-100001383

URL: <http://dx.doi.org/10.1081/PLN-100001383>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

MINERAL COMPOSITION OF FORAGE LEGUMES AS INFLUENCED BY ALUMINUM

V. C. Baligar,^{1,*} D. L. Grunes,² D. P. Belesky,¹
and R. B. Clark¹

¹USDA-ARS, Appalachian Farming Systems Research
Center, Beaver, West Virginia 25813-9423

²USDA-ARS, United States Plant, Soil, and Nutrition Lab,
Ithaca, New York 14853-2909

ABSTRACT

The nutritional quality of plants is primarily controlled by concentrations of essential nutrients and potentially detrimental substances, and these are influenced to a great extent by phytotoxic aluminum (Al). Alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.), and birdsfoot trefoil (*Lotus corniculatus* L.), cultivars were grown in nutrient solution culture under controlled conditions and the effects of Al on growth and mineral composition of plants were evaluated. With a few exceptions, Al significantly reduced shoot and root dry weights, and generally increased the concentrations of elements in shoots. Further increases in Al tended to reduce mineral concentrations in each species and cultivar. This was probably related to root injury, reduced dry matter accumulation at higher Al, and reduced nutrient demand at higher Al levels. In alfalfa and red clover cultivars, elemental equivalency ratios for

*Corresponding author.

K/Mg and $K/(Ca + Mg)$ increased, and ratios for Ca/P decreased in plants grown with Al. Forage with low Ca/P indicates poor quality, and high K/Mg and $K/(Ca + Mg)$ ratios indicates higher grass tetany hazard to animals. Most of the elemental concentrations and nutrient ratios were similar for Al-sensitive and Al-tolerant cultivars of alfalfa and red clover. The species and cultivars used in this study had inter- and intraspecific differences in growth and nutrient concentrations, both in the presence and absence of phytotoxic levels of Al.

INTRODUCTION

Aluminum in the growth medium can be detrimental to growth of legumes and can interfere with uptake of essential mineral nutrients by roots (1–3,5,17). Mineral nutrient efficiency ratios (ER = units of shoot dry weight produced per unit of element in shoots) of absorbed nutrients were reduced by phytotoxic levels of Al in birdsfoot trefoil, alfalfa and red clover (2,3,17). Aluminum reduced uptake of Ca and Mg in oats (*Avena sativa* L.) (6) and wheat (*Triticum aestivum* L.) (7,8). Reduction in Ca and Mg in forages might lead to mineral disorders in animals which consume the forage particularly hypomagnesia (grass tetany). Aluminum decreased Ca and Mg concentrations in plants more than K concentrations (4,7–9). These effects resulted in increases of $K/(Ca + Mg)$ ratios in plants, to enhance the potential for grass tetany hazard in animals. Grass tetany is a nutritional disease of ruminants caused by a deficiency of Mg in their diet (10). The incidence and severity of grass tetany increases in animals when Ca is also low. Grass and small grain forages with equivalent ratios of $K/(Ca + Mg)$ of 2.2 or greater (calculated as a mole charge per kilogram) are considered to be tetany prone. Reduction of this ratio to less than 2.2 improves the nutritional quality of forages (10,11). Macro- (Ca, Mg, K, S, P, and N) and micro- (B, Cu, Co, Fe, I, Mo, Mn, Se, and Zn) elements are essential to animals, and lack of these elements in forages limits animal production (12,13).

Differences in growth and mineral uptake are genetically controlled in plants, and variations in these characteristics have been reported in the presence or absence of phytotoxic levels of Al for white clover (*Trifolium repens* L.) (14,15), red clover (2,16), and alfalfa (3,17,18). This genetic potential of plants could be harnessed to produce forages that have adequate levels of needed nutrients to enhance good animal production on forages grown on acidic soil ecosystems.

Three nutrient culture experiments were conducted under controlled conditions to assess growth and shoot mineral nutrient concentrations and nutrient quality ratios of alfalfa, red clover, and birdsfoot trefoil grown at various



levels of Al. Fifteen entries of alfalfa and 23 entries of red clover were also evaluated.

MATERIALS AND METHODS

Growth Conditions

Experiments were conducted in a climatically controlled growth room with 14 h of $530 \mu\text{mol s}^{-1} \text{m}^{-2}$ light and 10 h of darkness. With lights on, temperature was 28°C at 60% relative humidity (RH), and with lights off, temperature was 28°C with 80% RH. Modified Steinberg solution (19) at pH 4.5, was used as the growth medium. The nutrient solution composition was $4.4 \text{ NO}_3\text{-N}$, $0.4 \text{ NH}_4\text{-N}$, 1.5 Ca , 0.3 Mg , 0.7 K (mmol L^{-1}) and 97 P , 115 S , 6.6 B , 0.6 Zn , 0.16 Cu , 0.1 Mo , 2.4 Mn , and 21.48 Fe ($\mu\text{mol L}^{-1}$). The Fe was added as equal amounts of FeSO_4 and Fe-DTPA. Aluminum was added as $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$.

Experiment 1

Seedlings of birdsfoot trefoil (cv 'Empire' and 'Viking'), red clover (cv 'Kenstar' and 'Tensas'), and alfalfa (cv 'Arc' and 'Oklahoma') were germinated in perlite, and on the ninth day 10 seedlings were transferred to 14-L polyethylene containers. High density styrofoam was used as a top to hold plants in place. Three levels of Al (0, 100, $200 \mu\text{M}$) were used and nutrient solution pH was adjusted to 4.5, and unadjusted thereafter. Water having pH 4.5 was added to the containers as needed to maintain water level. Solutions were not renewed during the study. Plants were harvested when 51 days old. A complete randomized design with three replications was used. Detailed experimental methods for this study are provided in Baligar et al. (3).

Experiment 2

Fifteen entries of 21-day-old alfalfa clones grown in a sand: perlite (1:1) mixture, were used for the study. Eight plants per alfalfa entry were suspended over 10-L polyethylene containers that were fitted with high density foam plastic tops. After 10 days in the nutrient solution, Al treatments (0, 75, $150 \mu\text{M}$) were introduced, pH was adjusted to 4.5, and no further pH adjustments were made during the course of the experiment. Solutions were not renewed during the study; however deionized water at pH 4.5 was added to compensate for water losses. The experiment was terminated after plants had been in the treatment



solutions for 25 days. A split-plot design was used, where cultivars were sub-treatments, and each experimental block had three replications. Cultivars and the line and growth conditions used for this study have been reported by Baligar et al. (17).

Experiment 3

Seeds of 23 entries of red clover were germinated and grown for 10 days in a mist bed on plastic screens fitted to plastic containers. Each of these containers with 10 plants were suspended over 14-L polyethylene containers. Plants were introduced to 0, 25, 50, 75, and 100 μM Al after one week of growth in nutrient solution at pH 4.5. The solutions were renewed at 2-week intervals, and at each renewal, pH was adjusted to 4.5. No adjustment in pH was made during the 2-week intervals. The experiment was terminated when the plants were 46 days old. A complete randomized design with two replications of each Al treatment and cultivar was used. Baligar et al. (2) reported the experimental method and cultivars of red clovers used in this study.

Harvest and Plant Analysis

At harvest, roots and shoots were separated, rinsed with deionized water, blotted dry, oven-dried at 70°C and weighed. Shoot samples were ground to pass a 0.50-mm mesh screen, and subsamples were wet-digested in $HNO_3/HClO_4$ (4:1) mixtures. Elements were determined by inductively coupled plasma (ICP) emission spectroscopy. Relative growth reductions (RGR) of shoots were calculated as follows:

$$RGR = [1 - (\text{shoot weight with Al} / \text{shoot weight without Al})] \times 100$$

where shoot weights were taken at 0 and 75 μM Al for alfalfa and at 0 and 50 μM Al for red clover.

RESULTS AND DISCUSSION

Aluminum Effect on Growth and Elemental Concentrations

Shoot and root dry matter yield for plants grown without Al as also growth reduction due to Al, nutrient uptake, and efficiency ratios have been reported (2–3,17). Increasing Al in the growth medium significantly reduced shoot and root weight for each legume species and of the different cultivars of each species



Al AND MINERAL COMPOSITION OF FORAGE LEGUMES

219

Table 1. Shoot Dry Weight (DW) and Concentrations and Ratios of Elements in Shoots of Birdsfoot Trefoil, Red Clover, and Alfalfa as Influenced by Aluminum Levels

Species/ Cultivar	Dry Wt			Shoot Elemental Concentrations							K/Mg (meq/ kg)
	Al (μM)	Shoot	Root	P (mg/g)	K (mg/g)	Mg (mg/g)	Fe ($\mu g/g$)	Mn ($\mu g/g$)	Zn ($\mu g/g$)	Cu ($\mu g/g$)	
		(g/10 plants)	(g/10 plants)								
Birdsfoot trefoil											
Empire	0	3.50	2.42	0.55	3.87	1.24	35.8	25.5	14.8	2.5	1.00
	100	0.34	0.28	0.82	9.89	1.73	34.4	30.2	30.5	4.7	1.78
	200	0.05	0.04	0.28	7.71	1.42	12.2	32.0	80.3	12.2	1.69
Viking	0	3.53	2.68	0.50	3.46	1.22	161.9	32.2	37.3	2.8	0.90
	100	0.44	0.33	0.56	9.14	2.38	34.0	37.8	27.1	4.7	1.19
	200	0.06	0.04	0.24	8.83	1.40	18.0	26.8	54.9	10.7	1.96
Red clover											
Kenstar	0	3.85	1.80	0.59	3.68	1.78	69.5	28.9	19.2	44.7	0.67
	100	1.13	0.40	0.76	12.87	1.95	27.5	31.9	28.3	5.2	2.06
	200	0.12	0.03	0.56	12.27	2.35	23.0	38.8	69.5	17.5	1.62
Tensas	0	6.07	1.63	0.74	3.50	1.81	54.4	24.2	19.6	49.2	0.61
	100	2.21	0.60	0.73	11.72	1.51	12.2	25.8	22.1	3.7	2.43
	200	0.10	0.04	0.51	12.10	2.31	17.0	37.7	57.3	14.4	1.63
Alfalfa											
Arc	0	6.40	3.05	0.40	3.26	0.73	14.4	27.4	15.8	3.2	1.51
	100	0.10	0.10	0.64	10.09	2.18	35.4	47.1	65.9	12.0	1.44
	200	0.05	0.04	0.65	9.48	2.51	35.5	64.6	96.9	23.2	1.17
Oklahoma	0	6.22	2.59	0.39	3.59	0.74	12.5	27.0	13.7	2.8	1.53
	100	0.07	0.06	0.62	10.02	2.14	39.0	58.3	64.4	14.3	1.46
	200	0.05	0.04	0.50	6.91	1.90	37.5	49.9	78.3	18.4	1.13
Analysis of variance—F value											
Species (S)	NS	NS	<i>b</i>	<i>b</i>	<i>b</i>	NS	<i>b</i>	<i>b</i>	<i>b</i>	NS	
Cultivar (C)	NS	NS	NS	<i>a</i>	<i>b</i>	NS	NS	NS	NS	NS	
T-Al (T)	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	NS	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	
S \times T	NS	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	
C \times T	NS	NS	NS	<i>b</i>	<i>b</i>	NS	<i>b</i>	<i>b</i>	NS	<i>a</i>	
Among T-Al (Linear)	<i>b</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>b</i>	NS	<i>b</i>	<i>b</i>	NS	<i>b</i>	

^{a,b}Significant at 0.05 and 0.01 levels of probability, respectively.

NS = Not significant.

(Tables 1–3). Mean shoot dry weight of alfalfa cultivars grown at 75 and 150 μ M Al was reduced by 29 and 62% compared to the control, respectively (Table 2). Mean shoot weight of red clover cultivars grown at 50 and 100 μ M Al was reduced by 75 and 93% compared to the control, respectively (Table 3). Increasing Al significantly reduced root weight of alfalfa and red clover cultivars. However, Al was more toxic to red clover roots than to alfalfa (Tables 2 and 3).





Table 2. Mean Shoot and Root Dry Weight, and Concentrations and Ratios of Elements in Shoots of 15 Alfalfa Cultivars as Influenced by AI

AI (μM)	Dry Wt.		Shoot Element Concentrations									Element Ratios				
	Shoot (g/plant)	Root (g/plant)	C (mg/g)	N (mg/g)	P (mg/g)	S (mg/g)	K (mg/g)	Ca (mg/g)	Mg (mg/g)	Zn (μ g/g)	Mn (μ g/g)	Ca/P	C/N	K/Mg (meq/kg)	K/(Ca + Mg) (meq/kg)	N/S
0	2.29	0.73	428	21.1	0.96	1.77	10.6	23.3	2.06	29.0	47.0	24.3	20.3	1.60	0.20	11.9
75	1.63	0.67	429	25.1	0.93	2.37	13.3	23.1	2.60	35.7	58.1	24.8	17.1	1.59	0.25	10.6
150	0.88	0.48	431	28.3	1.04	2.17	16.0	18.1	2.53	44.5	66.4	17.4	15.2	1.97	0.37	13.1
Analysis of variance—F value																
Treatment (AI)	<i>b</i>	<i>b</i>	ND	<i>b</i>	NS	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	NS	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	ND
Cultivar (C)	<i>b</i>	<i>b</i>	ND	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	ND
T-AI \times C	<i>b</i>	NS	ND	<i>a</i>	NS	<i>b</i>	NS	<i>b</i>	<i>b</i>	NS	<i>b</i>	<i>a</i>	<i>b</i>	NS	<i>b</i>	ND
Among T-AI (Linear)	<i>b</i>	<i>b</i>	ND	<i>b</i>	NS	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>b</i>	NS	<i>b</i>	<i>b</i>	ND

^{a,b}Significant at 0.05 and 0.01 levels of probability, respectively.

NS = Not significant.

ND = Not determined.



Table 3. Shoot and Root Dry Weight, and Concentrations and Ratios of Elements in Shoots of 23 Red Clover Cultivars as Influenced by Al

Al (μ M)	Dry Wt.		Shoot Element Concentrations							Element Ratios		
	Shoot (g/10 plants)	Root (g/10 plants)	P (mg/g)	S (mg/g)	K (mg/g)	Ca (mg/g)	Mg (mg/g)	B (μ g/g)	Fe (μ g/g)	Mn (μ g/g)	Ca/P	K/(Ca + Mg) (meq/kg)
0	5.98	1.51	1.45	1.32	12.2	16.1	1.9	11.8	58.9	36.7	11.1	2.0
25	3.49	1.17	1.56	1.58	15.8	16.2	2.1	14.2	60.7	42.6	10.4	2.3
50	1.51	0.61	1.81	1.77	21.5	16.7	2.4	15.7	71.3	51.1	9.2	2.8
75	0.81	0.23	1.79	1.58	22.7	9.5	1.8	15.2	56.8	37.7	5.3	3.9
100	0.42	0.10	1.96	1.78	22.9	8.2	1.7	16.9	67.3	31.8	4.2	4.2
Analysis of variance—F value												
Treatment Al	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>
Cultivar (C)	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>
T-Al \times C	<i>a</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>
Among T-Al												
Linear	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>
Quadratic	<i>b</i>	<i>b</i>	NS	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	NS	<i>b</i>	<i>b</i>	<i>b</i>
Cubic	NS	<i>b</i>	NS	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>

^{a, b}Significant at 0.05 and 0.01 levels of probability, respectively.

NS = Not significant.

Increases in Al from 0 to 200 μM increased shoot concentrations of K in all these species, and frequently the concentrations of Mg, Mn, and Zn too (Table 1). Increasing Al decreased concentrations of Fe in birdsfoot trefoil, and Fe, and Cu concentrations in red clover. Increasing Al increased Fe concentrations in alfalfa and Cu concentrations in birdsfoot trefoil and alfalfa (Table 1). Many elemental concentrations in each species and cultivars were lower than the dietary requirements of dairy and beef cattle (20–22).

Alfalfa grown with up to 150 μM Al had increased shoot concentrations of N, P, S, K, Mg, Zn, and Mn, but had reduced Ca (Table 2). Red clover grown with up to 100 μM Al had increased shoot concentrations for P, S, K, and B (Table 3). Increased shoot concentrations of Mg, Fe, and Mn in red clover were observed by increasing solution Al to 50 μM . Plants grown with further increases in Al tended to have reduced shoot concentrations of these elements (Table 3).

Reduction of Ca concentrations with increasing Al were similar in the red clover entries to those for alfalfa. Increases in concentrations of elements in shoots due to Al may have been related to reduced dry weight of shoots because of the concentrating effect of reduced growth. Further increases of Al phytotoxicity reduced shoot and root growth considerably, which resulted in reduced element concentrations in shoots.

Overall concentrations of Ca, Mg, Zn, and Mn in shoots of 15 alfalfa cultivars were sufficient to support normal plant growth (Table 2). However, concentrations of N, P, S, and K were at less than sufficient levels (23). In the study with 23 red clover cultivars (Table 3), the overall shoot concentrations of P, S, Ca, Mg, and B were at below sufficiency levels, whereas K, Fe, and Mn were at a sufficiency levels to support normal plant growth (23).

Shoot concentrations of S, K, Ca, Mg, Zn, and Mn observed for alfalfa (Table 2) and red clover (Table 3) cultivars were adequate for dietary needs of dairy and beef cattle (20–22). However, P concentrations were lower than dietary needs of ruminants. The dietary P needed by dairy and beef cattle is 2.0 to 4.8 mg P g^{-1} feed (20–22). The alfalfa cultivars had P concentrations of less than 2 mg g^{-1} , which were lower than ruminant dietary needs. The micro elements B, Cu, Mo, Fe, Mn, and Zn are essential for plants and animals, and I, Co, and Se are generally accepted as essential for livestock (13). Deficiency of these elements in forages could limit livestock production (12,13). Overall, Al tended to increase concentrations of Zn, Mn, B, Fe, and Mn in the legumes grown in our study, but reduction of shoot dry matter accumulation in each species and cultivar was considerable. This could lead to reduced uptake of essential elements by animals that consume such forages.

Barring a few exceptions, species, cultivars, Al-treatment, and interactions resulted in significant differences in concentrations of elements in shoots (Tables 1–3). With a few exceptions, overall significant linear responses were observed for elemental concentrations as Al in solution was increased.



Aluminum Effects on Forage Quality

Increasing the level of Al increased K/Mg ratios for birdsfoot trefoil and red clover (Table 1). However, this was not the case for alfalfa, where added Al markedly increased Mg concentrations (Table 1).

Gross and Jung (24) recommended use of the K/Mg equivalent ratio for legumes, rather than the K/(Ca + Mg) equivalency ratio, because legumes normally have higher Ca concentrations than grasses when grown in soil. The K/Mg ratios for alfalfa cultivars (Table 2) were 1.8 fold lower than those for red clover cultivars (Table 3). Gross and Jung (24) reported that alfalfa cultivars had higher K/Mg ratios than had cultivars of white clover, red clover, and birdsfoot trefoil, and that grass tetany incidence would be less in cattle consuming legumes other than alfalfa. The conclusions of Gross and Jung (24) were in agreement with data from three locations in West Virginia (25). It was noted in these studies that alfalfa was consistently lower in Mg than did red clover, and was almost always lower in Mg than did white clover.

An equivalent ratio of K/(Ca + Mg) greater than 2.2 in forages has been associated with grass tetany hazard in ruminants, and Mg concentration of 2.5 mg g⁻¹ in forages may be required to prevent grass tetany (10). Small grains or grass forages containing 2 mg g⁻¹ Mg or less, and more than 30 mg g⁻¹ of K on a dry weight basis, are likely to induce grass tetany (10). In our study, Mg concentrations in legumes were 1.7–2.6 mg g⁻¹, and K concentrations were 10.6–22.9 mg g⁻¹. Grass tetany occurred when grass Ca levels were 3.9 mg g⁻¹ in New Zealand, 5.2 mg g⁻¹ in The Netherlands, and 4.0 mg g⁻¹ in Norway (25). The Ca concentrations observed in our study ranged from 18 to 23 mg g⁻¹ for alfalfa (Table 2) and 8–17 mg g⁻¹ for red clover cultivars (Table 3). The high Ca concentrations in legumes compared to grasses and cereals might lead to reduced grass tetany hazard for animals. Inclusion of high proportions of legumes in grass mixtures might prevent the occurrence of grass tetany in animals grazing on acidic soils that normally have low Ca and Mg.

Increasing Al from 0 to 150 μ M in alfalfa, reduced Ca/P ratios from 24.3 to 17.4 (Table 2). In red clover, increasing Al from 0 to 100 μ M reduced Ca/P ratios from 11.1 to 4.2 (Table 3). Ratios of Ca/P of 1.0–2.0 are not detrimental to growth and bone formation in animals. Growth rates of calves were satisfactory at Ca/P ratios ranging from 1.0 to 7.0, and decreased performance occurred when calves were fed with forages containing higher or lower Ca/P ratios than these (21, 26). Smith et al. (27) did not find differences among lactating cows fed rations containing Ca/P ratios of 1.0, 4.0, and 8.0. The high ratios of Ca/P observed in our study were associated with lower P concentrations in both alfalfa and red clover (Tables 2 and 3). High Ca/P ratios in alfalfa compared to those in red clover could result in poor quality alfalfa forage. The high Ca/P ratios could also lead to decreased performance and nutrient conversion in animals consuming such forage.



Table 4. Average Response of Growth Parameters, Concentrations, and Ratios of Elements in Shoot of Al-Sensitive and Al-Tolerant Alfalfa and Red Clover Cultivars

Parameters	Alfalfa ^a		Red Clover ^b	
	Al-Sensitive	Al-Tolerant	Al-Sensitive	Al-Tolerant
Growth				
Shoot dry weight g/plant	1.34	1.77	0.11	0.18
Root dry weight g/plant	0.56	0.76	0.05	0.08
RGR ^c —shoot %	39.00	18.00	83.40	60.50
Shoot/root DM ratio	2.41	2.39	2.50	2.30
Concentration ^d				
C	430.0	426.0	—	—
N	26.0	21.0	—	—
P	0.9	0.8	1.9	1.7
S	2.4	2.0	1.8	1.8
K	13.4	11.2	21.5	22.0
Ca	23.3	22.0	17.0	17.1
Mg	2.9	2.1	2.4	2.3
Fe	—	—	75.2	72.5
Mn	59.7	45.1	49.9	52.5
Zn	25.5	28.0	—	—
Mineral ratios				
Ca/P	26.6	28.4	9.5	10.3
N/S	11.4	10.5	—	—
Equivalency ratios (meq/kg)				
K/Mg	1.50	1.70	2.92	2.92
K/(Ca + Mg)	0.26	0.23	0.54	0.55

^a Alfalfa, Al-sensitive where RGR \geq 35, Al-tolerant RGR \leq 23.

^b Red clover, Al-sensitive where RGR \geq 77, Al-tolerant RGR \leq 70.

^c RGR = $[1 - (\text{shoot wt with Al} / \text{shoot wt without Al})] \times 100$. Al levels for alfalfa were 0 and 75 μM and for red clover 0 and 50 μM .

^d Concentration mg/g for C, N, P, S, K, Ca, and Mg, and $\mu\text{g/g}$ for Fe, Mn, and Zn.

The N/S ratios ranged from 10.6 to 13.1 in alfalfa cultivars (Table 2), with the N/S ratio of 15.0 being recommended (13). Bouchard and Conrad (28) reported that N/S ratios of 12.0 were adequate for feed intake of lactating dairy cows. The S requirement for lactating dairy and beef cattle should be 1–2 mg g⁻¹ in diets (20–22). Concentrations of S in alfalfa shoots were 1.8–2.4 mg kg⁻¹, which were low for supporting good alfalfa growth, but appeared to be adequate for animal diets.

The C/N ratios in alfalfa declined from 20.3 to 15.2 when Al was increased from 0 to 150 μM (Table 2). This was due primarily to N concentrations increasing



from 21.1 to 28.3 mg g⁻¹. These levels of N would be low for support of good alfalfa growth.

It was frequently noted that cultivars, Al-treatments, and the interactions in the alfalfa and red clover cultivar studies had significant differences in elemental ratios of Ca/P, C/N, and N/S, and in equivalency ratios of K/Mg and K/(Ca + Mg) (Tables 2 and 3). With a few exceptions, elemental ratios gave significant linear and quadratic responses to Al treatment.

Concentrations and Quality Relative to Aluminum Tolerance

Aluminum-tolerant and Al-sensitive cultivars of alfalfa (Experiment 2) and red clover (Experiment 3) were compared for differences in growth and concentrations as also for equivalency and concentration ratios of elements when grown with toxic levels of Al (Table 4). The Al-tolerant cultivars of both alfalfa and red clover had higher shoot and root dry weights, lower RGR for shoots, and lower shoot/root dry matter ratios than those for Al-sensitive cultivars. Foy (5) reported similar observations for several plant species.

The elemental concentrations, mineral ratios, and equivalency ratios were generally similar for Al-sensitive and Al-tolerant cultivars. Exceptions were the higher concentrations of N, Mg, and Mn in Al-sensitive alfalfa cultivars. For alfalfa, K/Mg and K/(Ca + Mg) ratios were low because K was not high. The K/(Ca + Mg) ratios were also low for red clover. Indeed, equivalency ratios of K/(Ca + Mg) in both alfalfa and red clover were considerably lower than the 2.2 value, which could reduce grass tetany in cattle and sheep.

ACKNOWLEDGMENTS

The excellent technical assistance of Mr. M. D. Smedley and Ms. B. K. Sweeney is appreciated. We thank Drs. Susan E. Miyasaka and Zhenli He for reviewing this manuscript.

REFERENCES

1. Andrew, C.S.; Johnson, A.D.; Sandland, R.L. Effect of Aluminum on the Growth and Chemical Composition of Some Tropical and Temperate Pasture Legumes. *Aust. J. Agric. Res.* **1973**, *24*, 325–339.
2. Baligar, V.C.; Wright, R.J.; Kinraide, T.B.; Foy, C.D.; Elgin, J.H., Jr. Aluminum Effects on Growth, Mineral Uptake, and Efficiency Ratios in Red Clover Cultivars. *Agron. J.* **1987**, *79*, 1038–1044.



3. Baligar, V.C.; Wright, R.J.; Fageria, N.K.; Foy, C.D. Differential Response of Forage Legumes to Aluminum. *J. Plant Nutr.* **1988**, *11*, 549–501.
4. Baligar, V.C.; Smedley, M.D. Response of Forage Grasses to Aluminum in Solution Culture. *J. Plant Nutr.* **1989**, *12*, 785–795.
5. Foy, C.D. Physiological Effects of Hydrogen, Aluminum and Manganese Toxicities in Acid Soil. In *Soil Acidity and Liming*; Adams, F., Ed.; 1984; Agronomy **1984**, *12*, 57–97.
6. Grimme, H. In *The Effect of Al on Mg Uptake and Yield of Oats*, Proceedings of 9th International Plant Nutrition Colloquium; Sciafe, A., Ed.; Warwick University: Farnham Royl Slough, UK, 1982; 198–203.
7. Grunes, D.L.; Ohno, T.; Huang, J.W.; Kochian, L.V. Effects of Aluminum on Magnesium, Calcium, and Potassium in Wheat Forages. In *Magnesium*; Golf, S.; Dralle, D.; Vecchiet, L., Eds.; John Libbey: London, England, 1993; 79–88.
8. Huang, J.W.; Grunes, D.L. Potassium/Magnesium Ratio Effects on Aluminum Tolerance and Mineral Composition of Wheat Forage. *Agron. J.* **1992**, *84*, 643–650.
9. Rengel, Z.; Robinson, D.L. Aluminum Effects on Growth and Micronutrient Uptake by Annual Ryegrass. *Agron. J.* **1989**, *81*, 208–215.
10. Mayland, H.F.; Grunes, D.L. Soil-Climate-Plant Relationships in the Etiology of Grass Tetany. In *Grass Tetany*; Rendig, V.V.; Grunes, D.L., Eds.; American Society of Agronomy Special Publication 35, Madison, WI, 1979; 123–175.
11. Grunes, D.L.; Welch, R.M. Plant Contents of Magnesium, Calcium, and Potassium in Relation to Ruminant Nutrition. *J. Anim. Sci.* **1989**, *67*, 3485–3494.
12. Kubota, J.; Welch, R.M.; Van Campen, D. Soil-Related Nutritional Problem Areas for Grazing Animals. *Adv. Soil Sci.* **1987**, *6*, 189–215.
13. McDowell, L.R. *Minerals in Animal and Human Nutrition*; Academic Press: New York, NY, 1992.
14. Caradus, J.R. Genetic Differences in Phosphorous Absorption Among White Clover Populations. In *Genetic Aspects of Plant Nutrition*; Saric, M.R.; Loughman, B.C., Eds.; Martinus Nijhoff Publishers: Dordrecht, The Netherlands, 1982; 441–445.
15. Snaydon, R.W. The Growth and Competitive Ability of Contrasting Populations of *Trifolium repens* on Calcareous and Acidic Soils. *J. Ecol.* **1962**, *50*, 549–447.
16. Hunt, I.V.; Frame, J.; Harkess, R.D. Removal of Mineral Nutrients by Red Clover Varieties. *J. Br. Grass. Soc.* **1976**, *31*, 171–179.
17. Baligar, V.C.; Elgin, J.H., Jr.; Foy, C.D. Variability in Alfalfa for Growth and Mineral Uptake and Efficiency Ratios Under Aluminum Stress. *Agron. J.* **1989**, *81*, 223–229.



18. Baligar, V.C.; Elgin, J.H., Jr.; Wright, R.J.; Fageria, N.K. Genetic Diversity for Nutrient use Efficiency in Cultivars and Exotic Germplasm Lines of Alfalfa. In *Genetic Aspects of Plant Mineral Nutrition*; Bassam, E.; Dambroth, M.; Loughman, B.C., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1990; 533–538.
19. Foy, C.D.; Fleming, A.L.; Burns, G.R.; Armiger, W.H. Characterization of Differential Aluminum Tolerance Among Varieties of Wheat and Barley. *Soil Sci. Soc. Am. Proc.* **1967**, *31*, 513–521.
20. NRC (National Research Council). Nutrient Requirement of Beef Cattle, 6th Edn.; National Academy Press: Washington, DC, 1984.
21. NRC (National Research Council). Nutrient Requirement of Dairy Cattle, 6th Edn.; National Academy Press: Washington, DC, 1988.
22. NRC (National Research Council). Nutrient Requirements of Beef Cattle, 7th Edn.; National Academy Press: Washington, DC, 1966.
23. Jones, J.B., Jr.; Wolf, B.; Mills, H.A. *Plant Analysis Handbook*; Micro-Macro Publishing: Athens, GA, 1991.
24. Gross, C.F.; Jung, G.A. Magnesium, Ca, and K Concentration in Temperate-Origin Forage Species as Affected by Temperature and Mg Fertilization. *Agron. J.* **1978**, *70*, 397–403.
25. Grunes, D.L. Uptake of Magnesium by Different Plant Species. In *Role of Magnesium in Animal Nutrition*; Fontenot, J.P.; Bunce, G.E.; Webb, K.E., Jr.; Allen, V.G., Eds.; Proceedings John Lee Pratt International Symposium, Virginia Polytechnic Institute and State University: Blacksburg, VA, 1983; 23–38.
26. Wise, M.B.; Ordoveaa, A.L.; Barrick, E.R. Influence of Variation in Dietary Calcium: Phosphorus Ratio on Performance and Blood Constituents of Calves. *J. Nutr.* **1963**, *79*, 79–84.
27. Smith, A.M.; Holck, G.L.; Spafford, H.B. Symposium: Reevaluation of Nutrient Allowances for High-Producing Cows. I. Calcium, Phosphorus and Vitamin D. *J. Dairy Sci.* **1966**, *49*, 239–243.
28. Bouchard, R.; Conrad, H.R. Sulfur Requirement of Lactating Dairy Cows. I. Sulfur Balance and Dietary Supplementation. *J. Dairy Sci.* **1973**, *56*, 1276–1282.



Request Permission or Order Reprints Instantly!

Interested in copying and sharing this article? In most cases, U.S. Copyright Law requires that you get permission from the article's rightsholder before using copyrighted content.

All information and materials found in this article, including but not limited to text, trademarks, patents, logos, graphics and images (the "Materials"), are the copyrighted works and other forms of intellectual property of Marcel Dekker, Inc., or its licensors. All rights not expressly granted are reserved.

Get permission to lawfully reproduce and distribute the Materials or order reprints quickly and painlessly. Simply click on the "Request Permission/Reprints Here" link below and follow the instructions. Visit the [U.S. Copyright Office](#) for information on Fair Use limitations of U.S. copyright law. Please refer to The Association of American Publishers' (AAP) website for guidelines on [Fair Use in the Classroom](#).

The Materials are for your personal use only and cannot be reformatted, reposted, resold or distributed by electronic means or otherwise without permission from Marcel Dekker, Inc. Marcel Dekker, Inc. grants you the limited right to display the Materials only on your personal computer or personal wireless device, and to copy and download single copies of such Materials provided that any copyright, trademark or other notice appearing on such Materials is also retained by, displayed, copied or downloaded as part of the Materials and is not removed or obscured, and provided you do not edit, modify, alter or enhance the Materials. Please refer to our [Website User Agreement](#) for more details.

[Order now!](#)

Reprints of this article can also be ordered at

<http://www.dekker.com/servlet/product/DOI/101081PLN100001383>